THE VARIATIONS OF GLACIERS. IX.[1]

THE International Committee on Glaciers met in Vienna last summer, and the retiring president, Professor S. Finsterwalder, presented a report to the International Congress of Geologists, of which the following is a brief summary:[2]

Although the committee has been at work only nine years, a time too short for very general results, still we can say that the thirty-five years' period which Brückner found in the variations of the Alpine glaciers applies also to glaciers in other parts of the world. It is also probable that there are longer climatic periods than this whose course is very complicated; moreover, the individual character of the variations of special glaciers is, without doubt, dependent upon the topography of their basins. We therefore have to do with variations of a very complicated character, as they depend both upon climatic changes and upon individual characteristics. But we can say, in general, that the dominating tendency of glaciers at the present time is to retreat. There are many exceptions to this rule, the reasons for which are not understood. The Mont Blanc group showed some tendency to advance in the eighties, and within the last twenty years this advance has been transferred to the most easterly Alps, though not advancing regularly over the intervening regions.

The Vernagtferner presents the most remarkable phenomena. This glacier increased 400^{m} in length between 1897 and 1902, which is not so extraordinary for it; but, in addition, the velocity of flow in a certain profile near the end increased from 17^{m} to over 250^{m} per year, and then suddenly within one year sank back to 80^{m}. The Vernagtferner is unique in other ways, and the careful study of its characteristics will add greatly to our knowledge of glaciers.

Professors Forel and Richter have offered explanations of the

[1] The earlier reports appeared in this JOURNAL, Vol. III, pp. 278–88; Vol. V, pp. 378–83; Vol. VI, pp. 473–76; Vol. VII, pp. 217–25; Vol. VIII, pp. 154–59; Vol. IX, pp. 250–54; Vol. X, pp. 313–17; Vol. XI, pp. 285–88.

[2] *Comptes rendus du Congrès géologique international de Vienne* 1903, pp. 161–69.

apparent irregularities of glacier variations. The increase in snowfall in the reservoir results in a thickening of the upper part of the glacier, which thickening then progresses down the glacier, somewhat like a wave, more rapidly than the ice itself. The ice thus advances faster than it melts, and the glacier is pushed farther down its valley. When the supply in the reservoir diminishes, the pressure from behind also diminishes, and the ice moves less rapidly and melts back.

Professor Finsterwalder then takes up the study of an ideal glacier, subject to periodic variations of thickness at the névé line, and subject to uniform melting along its whole length; and finds a mathematical equation which represents the changes in thickness and length which the glacier undergoes. Although these conditions are not exactly those which a glacier experiences, still they are near enough to give results which correspond fairly well with what is actually observed. The solution of the equation shows that the glacier in advancing takes a steep slope in front and moves with considerable velocity, and during the retreat takes a very gentle slope in front and its velocity is much diminished. The variation in thickness at the névé line produces a much greater relative variation in the length of the glacier, and the change at the end occurs later than the change at the névé line. Under these conditions the glacier advances slowly and retreats rapidly. This is in contradiction to experience, as glaciers usually advance rapidly and retreat slowly. This contradiction probably comes from the fact that we have assumed a uniform variation at the névé line, which, however, is probably not at all regular, but makes a rapid increase and a slow diminution. If now we introduce a variable rate of melting, and assume that it has the opposite phase to the variation of thickness at the névé line, we find the variation in length increased and the state of minimum existing for a longer time, which Forel has described as characteristic of glaciers. It thus appears that the Forel-Richter theory is, in general, upheld by mathematical analysis; but there are many peculiarities which are still unexplained. In the observations of the Vernagtferner glacier very great variations of velocity were found without corresponding increases in thickness.

Lately Hess has shown that ice yields more rapidly to a given

force as the time of application of the force increases. This might explain some of the difficulties, but many difficult questions of glacier physics arise in this connection.

The International Committee serves as a natural point of union for all investigators of glacier phenomena, and is doing good work in encouraging glacier studies.[1]

The following is a summary of the eighth annual report of the International Committee on glaciers:[2]

REPORT OF GLACIERS FOR 1902.

Swiss Alps.—Of the ninety-five glaciers which are being observed, seventy-eight were measured in 1902. The great majority of them are in a state of recession, and it is probable that the 680 other Swiss glaciers are receding also. The recession is therefore general, though there is a slight tendency this year to advance, shown especially among the glaciers in the southwest Bernese Alps. The little glacier of Boveyre, which has been advancing for ten years as a result of a great increase in material due to an avalanche, has begun to retreat.[3]

Eastern Alps.—On the south side of the Ortler, two glaciers have retreated $3.5–11^{m}$; one has probably made a slight advance. In the Silvretta group three glaciers show a retreat of $400–500^{m}$ since the last maximum in 1850–60. In the Oetzthal the Vernagtferner, which last year showed an advance of 50^{m} and a remarkable increase in velocity of from 210^{m} to 240^{m}, has suddenly decreased its speed to not more than one-third of its highest value; it has, however, advanced 20^{m}, and has swollen in its lower part. Its neighbor, the Guslarferner, has been stationary for many years.

[1] Professor Harry Fielding Reid, of Baltimore, was elected president of the committee for the ensuing three years, and M. E. Muret, of Lausanne, was re-elected as secretary. Professor Nathorst retired from the committee and was elected a corresponding member. Baron G. de Geer was elected to succeed him as representing the Arctic regions. Colonel J. von Schokalsky had already been elected to succeed the late Professor J. Mouschketow, who took such an active part in the work of the committee. The following additional corresponding members were elected: Professor Dr. A. Blümcke, of Nuremberg;; Professor Dr. Hans Hess, of Ansbach; Professor Dr. A. Penck, of Vienna; and Mr. George Vaux, of Philadelphia.

[2] *Archives des sciences physiques et naturelles*, Vol. XV, pp. 661–77; Vol. XVI, pp. 86–104.

[3] Report of Professor *Forel* and M. *Muret*.

Borings have been made in the Hintereisferner to determine its thickness. It has been completely pierced at a distance of 1,860^{m} from the end, where a thickness of 152.8^{m} was found. This glacier has retreated 94^{m} in the last eight years, and its velocity of flow has been reduced 25–30 per cent. Hochjochferner, near by, has retreated only 1^{m}, but has become somewhat thinner. Diemferner deserves special attention; it has advanced 30^{m} in the last two years, and 144^{m} since 1893. It has suffered a considerable change in form, and in the upper regions its sides very nearly reach the top of the old moraines.

In the same general neighborhood seven glaciers have retreated 6–20^{m} since 1891; and six others have retreated 21–90^{m} since 1899; two of these were advancing a few years ago. One glacier observed in the Stubai group is in continued retreat. In the Zillerthal the Schwarzenstein glacier is retreating, but more slowly than last year. The Horn Glacier has ceased to advance and has retreated 4^{m}, while the Waxegg has advanced 14^{m} on the average, and at one point 38^{m}. In the Venediger region eight glaciers show recessions of from 2–17^{m}. The Krimmlerkees, which shows the greatest retreat this year, was advancing last year.

In the Glockner group two glaciers have retreated 7–11.5^{m}, while the Pasterze is stationary.

In the Sonnblick group three glaciers show recessions of 5–20^{m} in two years. The Krummelkees, which advanced 7^{m} from 1899 to 1901, has been stationary since then.

In the Ankogl group two glaciers are retreating, but only half so fast as last year. On the other hand, the great Elendkees has changed its slight decrease of last year to a slight increase this year.

On the whole, the retreat is more rapid this year than in preceding years; nevertheless, a few glaciers are still advancing. We must mention that the Gepatschferner has been steadily retreating since 1886, when exact measures began.[1]

Italian Alps.—The Marmolada Glacier has retreated very considerably during the last forty years, though we cannot say what it is doing at the moment. The upper regions show signs of diminishing, but the growth before 1883 was made evident by the ice

[1] Report of Professor *Finsterwalder.*

closing up a grotto used as a sleeping-place by the Italian Alpine Club. This grotto remained closed from 1884 to 1900. The Cristal, Sorapiss, and Kellerwand Glaciers have all retreated from a fraction of a meter to 3^m. The snow-fields of Monte Cavallo show a considerable increase in size. The Lys Glacier, Monte Rosa, has retreated about 25^m, shows a marked change in its form, and reveals newly deposited moraines. In general, the retreat of the Italian glaciers has continued, but the snowfall has increased.[1]

French Alps.—Many glaciers have been observed under the direction of the French Committee on Glaciers, with the following results: On Mont Blanc the Bossons has greatly diminished; and the Mer de Glace, stationary for some time, now shows a marked recession.

In the Maurienne eleven glaciers are retreating; one has been stationary since 1892. The Glacier des Sources de l'Arc has retreated $1,250^m$ horizontally and 300^m in altitude since 1873. In the Grandes Rousses the Glacier des Quirlies has retreated about 25^m since 1899, and the Grand Sablat about 35^m. The Glacier de la Selle has retreated $600–800^m$ in the last thirty years. The Glacier des Étançons has retreated greatly, probably 100^m in the last fifteen years. Of its two tributaries which are now separated, one is advancing and the other is retreating.

The Pyrenees.—The advance of the end of the nineteenth century has affected the Glacier de Vignemale, which has inrceased notably in thickness, though it has not advanced. The glaciers, in general, are distinctly retreating. Of the twenty observed, fifteen are retreating, and the others are either stationary or possibly growing, although none show any real advance from 1901 to 1902.[2]

Scandinavian Alps: Norway.—The summer of 1901 was particularly warm in Norway, so that the glaciers melted rapidly, and the snow-fields diminished to an extent never before seen. Many glaciers were retreating, and the glacial streams were much higher than usual. On the other hand, during the summer of 1902 the snow remained very late. Several glaciers of Galdhötind advanced $15–20^m$, and several receded, perhaps as much. On August 11, the glacier lake of Mjölkedalsvand was suddenly emptied and caused an inundation. Two glaciers near Olden are retreating.

[1] Report of Professor *Porro*. [2] Report of Professor *Kilian*.

In the neighborhood of Folgefon several glaciers were retreating rapidly in the summer of 1901, whereas in 1902 they were advancing.

Sweden.—The Mika Glacier has advanced 5^m since 1901, and the Solta 20^m since 1900. The Skuova has apparently been stationary since 1897.[1]

Polar regions.—An expedition was sent to Greenland to study the inland ice between latitudes 68° 30′ and 69° 20′. Surveys of the Jakobshavn Fjord and the border of the inland ice to the south were made on a large scale. Photographs were also taken from marked points which may be used for future comparison. All the glaciers of the Jakobshavn Fjord are notably retreating; the rocks for 5.5^m above the present surface of the large glacier are entirely free of lichens, and the tongue of the glacier is 4^{km} shorter than in 1883. The small glaciers flowing from the tributary fjords of the Jakobshavn show a similar, but smaller, retreat. Farther south, near Orpigsuit, the edge of the inland ice seems to be retreating, as the rock immediately above it is free of lichens and is covered with fresh striæ. Photographs of the nunataks were taken which will serve to determine future variations.

The Swedish expedition to the South Pole visited Royal Bay in the Island of South Georgia. Ross Glacier, which had retreated, according to the German South Polar Expedition, $800–900^m$ between 1882 and 1883, has since then advanced to the point where it stood in 1882.[2]

Himalaya.—The Taschiny Glacier in Kashmir was retreating in 1875 and advancing in 1886. Some small glaciers in the Panjal Range were retreating before 1884 and advancing slightly some years later. In the Nun Kun the glaciers were advancing in 1902.

In the Karakorum Range several glaciers in Schigar Valley advanced for eight or ten years before 1895. In the Saser-Nubra Mountains a slight advance took place in 1896.[3]

Caucasus.—The four glaciers on Mount Kazbek which have been retreating for some time have become stationary, and great accumulations of snow seem to indicate the beginning of a new advance. The summit of Kazbek, which in 1900 was almost free of snow, is now covered to a considerable depth. In the valley of the Guisel-

[1] Report of Dr. *Oyen.* [2] Report of Dr. *Steenstrup.* [3] Report of M. *Chas. Rabot.*

Don the Djimara Glacier is still retreating, as are also two glaciers in the valley of the Ouroukh. The Mayl Glacier, on the northern slope of Mount Kazbek, was the scene of two terrible outbreaks which destroyed the baths of Kermadon in July, 1902. Two avalanches, originating in seven large snow-fields, came down a lateral gorge, and then passed over the surface of the glacier, following a course six miles long. The slopes of the mountains are not steep enough to cause this catastrophe, and it is probable that it was induced by an earthquake.

Siberia.—A number of small glaciers exist near the sources of the Oka River in the mountains southwest of Lake Baikal. Some of these were described by M. Radde in 1885. They are at present much smaller than they were then, and one of them seems to be on the point of disappearing. The Alatau or Kuznezk Mountains, 200 or 300 miles north of the Altai, do not contain any glaciers at present, but they show traces of former glaciation in the smoothed rocks and large moraines. In the Alatau of Sungaria there are many glaciers; those on the northern slope being generally larger than those on the southern. Two of the former have been surveyed. The mean height of the peaks in this portion of the range is about 13,000 feet. There are many glaciers in the Tyan Shan mountains which are rarely visited. The peaks of this chain have altitudes of from 16,500 to 17,500 feet; a new determination of the height of Mount Khantengri makes it 22,600 feet. Some of these glaciers are in a marked state of retreat; others do not indicate any definite variations. It seems in general that, if the glaciers are decreasing, there must be shorter intervening periods of growth, at least for some of the glaciers.[1]

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1903.[2]

In May, 1903, the Muir Glacier was visited for the first time since the earthquake of 1899. Mr. C. L. Andrews, deputy collector of customs at Skagway, and Mr. Case went from Skagway to the Muir Glacier in an open boat, photographed the end of the ice,

[1] Report of M. *Schokalsky*.

[2] A synopsis of this report will appear in the *Ninth Annual Report* of the International Committee. The report on the glaciers of the United States for 1902 was given in this JOURNAL, Vol. XI, pp. 287, 288.

and showed by a map the changes which have taken place there. They found that the ice-front had retreated to a distance of from 3 to 3½ miles from its former position, and almost the whole inlet was covered with floating ice very closely packed together. The ice-front now passes from the base of Mount Case northwesterly to the two small nunataks opposite, which have become united into one by the lowering of the ice. It then passes southwesterly to the corner of the large nunatak which separates Morse Glacier from the Muir. An area of 4⅔ square miles has thus been taken from the glacier and added to the inlet. An area of 9 square miles of the inlet is closely covered with floating ice. The amount of ice which has been broken off from the glacier—if we assume an average thickness of 700 feet, which is probably not far wrong—amounts to about 91,000 million cubic feet. This is about fourteen times the amount formerly discharged annually into the inlet.[1]

The ice forms a terrace along the eastern side of the mountains, and Dirt Glacier ends as an independent tide-water glacier. Morse Glacier, which had already become an alpine glacier, separated from the Muir, no longer has its valley closed up by the latter's ice.[2]

The new ice-front is composed of two parts. The eastern part from Mount Case to the nunatak consists of ice which is practically stationary, whereas the western part receives all the active flow of the glacier. This portion does not differ materially in breadth from the old ice-front, and receives practically all the ice which was formerly discharged into the inlet. It stands up as a vertical wall probably about 200 feet above the water. In 1890 the surface of the ice where the glacier now ends was 500–600 feet above sea-level, so that this surface has been lowered 300–400 feet. The fact that the ice stands up as a vertical wall makes it probable that the water is fairly deep at this point, though probably not as deep as at the old ice-front. If this is so, the velocity of the ice near the present end is probably a little greater than near the old end, as the section is somewhat less. This causes a tendency to advance, but the position of the end will probably remain almost stationary for some time; for if it advances materially beyond its present position, it will find no

[1] "Studies of Muir Glacier," *National Geographic Magazine*, Vol. IV (1892), p. 51.

[2] C. L. ANDREWS, "Muir Glacier," *ibid.*, Vol. XIV (1893), pp. 441–45.

support on the east; it will broaden out, and will offer a longer line for breakage. If, on the other hand, there should be any material retreat, the ice-front would again become longer, resulting in still more rapid retreat, until, perhaps, the glacier withdraws above tide-level.

There are eight glaciers of considerable size within easy reach of Skagway. These glaciers have been under observation by Mr. Andrews, who expects to continue to observe them. They are all retreating rapidly. Denver Glacier melted back 40 feet in two months in the summer of 1903. The "S" Glacier and the Upper Glacier have been retreating at the rate of 30 or 40 feet a year since 1898 (*Andrews*).

The Mendenhall Glacier near Juneau retreated at the rate of 40 or 50 feet annually between 1892 and 1901. Immediately bordering its sides and end the ground is free of vegetation, but the shrubs and trees gradually increase in extent and size as we go farther from the glacier, either down its valley or up the mountain side. This increase in the age of the trees indicates the rate at which the glacier has retreated. It is very remarkable how rapidly trees have grown in this region, attaining a thickness of nine inches in twenty-five years and of nearly two feet in one hundred years[1] Mr. Fernow has also noted the remarkably rapid growth of trees at the entrance of Glacier Bay, where trees only forty or fifty years old were 36 inches in diameter and 80 feet high.[2]

Throughout Oregon and Washington the last three years have been marked by excessive precipitations, and the snowfall of last year seemed to be the greatest of the three; but there is no evidence that this has yet resulted in the advance of the glaciers. Mount Baker is an interesting mountain, but it has received very little attention. It was ascended last summer by Mr. C. E. Rusk, who writes me that there are about ten glaciers on the mountain. Two of these, which he had the opportunity to examine, showed signs of marked retreat in recent years.

The Eliot Glacier on Mount Hood has retreated slightly since

[1] MARSDEN MANSON, "Forest Advance over Glaciated Areas in Alaska and British Columbia," *Forestry Quarterly*, Vol. I (1903), pp. 94–96.

[2] See *Harriman Expedition*, Vol. II, pp. 249–52.

1901. (*Langille.*) The glaciers on the south side of Mount Hood also show evidence of retreat during the same interval. (*Montgomery.*)

There are two or three glaciers on Mount Jefferson, but we have no evidence as to their variations. The peaks of the Three Sisters surround a large amphitheater five miles wide, which opens toward the east and formerly held a large glacier, but this has shrunk so much that it has now broken up into four small glaciers. There are three others on the outer slopes of the mountain. The moraines of the glaciers in the amphitheater stand up 30 or 40 feet above their surface. They are still fresh and free of vegetation, showing that this diminution of the ice has taken place in comparatively recent years. The reduction in thickness of the ice seems to be more marked than the reduction in length. Ice still remains under the moraines, which is a further indication of the short time since they were formed. The double crests which some of these moraines present are ascribed to the melting of the ice under them. One of these glaciers showed in its Bergschrund projecting layers of ice separated by layers of dirt similar, on a small scale, to the projecting layers of ice found at the end of Greenland glaciers.[1] In the present instance, however, these projections are not ascribed to shear, but to differential melting; for where the snow is shaded from the sun the projections do not exist. (*Russell.*)

Comparison of photographs of Lyell Glacier in California taken in 1883 by I. C. Russell and in 1903 by G. K. Gilbert show only very slight recession, whereas the McClure Glacier, close by, has suffered a marked retreat during the same interval. (*Gilbert.*) This difference may be due in part to the shapes of the two glaciers, Lyell being much broader than it is long, whereas the McClure presents a definite tongue.

Professor LeConte has found a new glacier just below the eastern precipice of Mount Jordan, in northern California, and thinks that there are other small glaciers along the eastern slope of the Sierras in this neighborhood. There has been less snow in the Sierras

[1] I. C. RUSSELL, "Glacier Cornices," JOURNAL OF GEOLOGY, Vol. XI (1903), pp. 783–85.

of California this year than for many years past, and probably all the glaciers are retreating. (*LeConte.*)

The Chaney and Sperry Glaciers in Montana show a marked retreat. The former, though a small glacier, has retreated 200 yards or more in the last eight years. (*Chaney.*)

The snowfall on the Arapahoe Glacier in Colorado was unusually small in 1902. In 1903, however, it was unusually large, and seems to have produced a noticeable effect on this little glacier. The ice is somewhat thicker and the front slope of the glacier steeper, but there is no apparent change in length, except at two points where streams have effected a slight recession. From September, 1901–2, the precipitation was below normal and the temperature above normal at the Weather Bureau stations nearest to this glacier, whereas it was just the reverse from 1902–3. Silt was found on the moraines similar to that found last year, and as it is impossible to suppose that the glacier has advanced over the moraine and retreated again within a year, the former explanation of this silt, which required rather violent fluctuations of the glacier, must be abandoned. It is probable that the silt is due to dust blown from the mountains upon the snow and left on the moraine when the snow melted. This is a more satisfactory explanation, but it shows nothing with regard to the glacier changes.[1]

HARRY FIELDING REID.

GEOLOGICAL LABORATORY,
John Hopkins University,
March 17, 1904.

NOTE.—Since the above report was written, the third volume of the Harriman Alaska Expedition, on *Glaciers and Glaciation*, has appeared. It is written by Mr. G. K. Gilbert, and is a valuable contribution to our knowledge of the Alaskan coast glaciers. Mr. Gilbert collates all information regarding the variations of these glaciers up to 1899, and adds the observations made by himself and by other members of the expedition. The positions of the ends of many glaciers are shown by pictures and maps. The glaciers discussed are too numerous to be named here, but we must mention the general fact that the glaciers of Glacier Bay and of Disenchantment Bay show very great recessions during the last hundred

[1] JUNIUS HENDERSON, "Arapahoe Glacier in 1903," JOURNAL OF GEOLOGY, Vol. XII (1904), pp. 30–33.

years, whereas those of the southwestern slopes of the Fairweather Range and those of Prince William Sound have quite lately been as extensive as they have probably been for several centuries. Mr. Gilbert makes some general suggestions of a theory to explain such curious anomalies. He also presents clearly the very striking evidence which the topography of the Alaskan coast offers in favor of the power of glaciers to erode their channels. The volume concludes with a theoretical discussion of the influence of the sea on the pressure which tide-water glaciers exert on their beds below sea-level.